Part 9
GENERATOR, MOTOR AND BUS PROTECTION
GENERATOR PROTECTION
The protection system design will depend on the size of the generating unit and the types of faults or abnormal operating conditions.

The fault types are classified as:
- Overload protection and overcurrent problems
- Stator electrical faults
- Rotor electrical faults
- Failure of prime mover (mechanical problems)
- Failure of the field circuit

The following protection schemes are used:
- Overload protection, and overcurrent protection
- Overvoltage and under-voltage protection
- Unbalanced loading (Currents) –sequence relay
- Over-excitation
- Loss of excitation
- Loss of synchronism
- Phase faults
- Earth faults
- Abnormal frequencies motoring
- Over speeding
- Excessive vibration
- Internal faults,
- Stator and rotor thermal protection, and field ground.
Generator Protection Application Simplified One-Line Diagram
1. Generator protection using differential protection schemes

Differential protection is used with biased circulating current scheme to protect the generator against the failure of:

• winding insulation
• failure of the field circuit
• prime mover failures.

The protection scheme is shown in Fig. Normally differential protection is used for generators larger than or equal to 20MW.
Example 1
Figure shows a biased percentage differential relay applied for the protection of synchronous generator windings. The relay has 0.1A minimum pick up current and a 10 %,if:-
(a) The fault has occurred near the grounded neutral end of the generator when the generator is carrying load. As a result, the currents flowing at each end are as shown in the figure. **Would the relay operate or no?**
(b) at the given value of fault current in (a ) above ,the relay would operate if the generator was carrying no load ?
(c) On the same diagram , show the relay operating characteristics and the points that represent the operating and restraining currents in the relay for the two conditions.
(a) Fault under load conditions

\[ I_{s1} = 420 \times \frac{5}{500} = 4.2\, \text{A} \]

\[ I_{s2} = 400 \times \frac{5}{500} = 4\, \text{A} \]

\[ I_{op} = I_{s1} - I_{s2} = 4.2 - 4 = 0.2\, \text{A} \]

The **restrain coil average** current is

\[ I_r = \frac{I_{s1} + I_{s2}}{2} = 4.1\, \text{A} \]

**But the relay is setting to operate with less than 10% of the restrain current**

\[ I_{op} \geq \left[ \frac{10}{100} \times 4.1 \right] = 0.41\, \text{A} \]

(at this value the relay is set to operate and 0.2A is less than this value, therefore the relay will not operate)
(b) Generator **fault under no load conditions**

The fault current same as (a) hence:

\[
I_f = 420 - 400 = 20A
\]

\[
I_{f1} = 0
\]

\[
I_{f2} = 20 \times \frac{5}{500} = 0.2A
\]

Which flows through the operating coil

\[
I_{s2} = 0A
\]

\[
I_{s1} = I_{f2} = 0.2A
\]

\[
I_{op} = I_{s1} - I_{s2} = 0.2 - 0 = 0.2A
\]

\[
I_r = \frac{I_{s1} - I_{s2}}{2} = 0.1A
\]

Since \(I_{op} > I_r\), (0.2 > 0.1)A **the relay will operate.**

(c) Relay characteristics
GENERATOR PROTECTION APPLICATIONS

1-PHASE FAULT PROTECTION: Causes thermal damage to insulation, windings, and the core, and mechanical torsional shock to shafts and couplings.

2-GROUND-FAULT PROTECTION: Causes is insulation failure.

3-LOSS-OF-FIELD (EXCITATION) PROTECTION: Caused by operator error or excitation system failure, accidental tripping of the field breakers, or flashover of the exciter commutator.

4-OVEREXCITATION PROTECTION: Failure in the excitation system can also cause over-excitation. Similar problems can occur with the connected transformer.

5-OVERVOLTAGE PROTECTION: May occur during a load rejection or excitation control failure.

6-UNBALANCED CURRENTS: Can cause unbalanced three-phase currents in the generator.

7-ABNORMAL FREQUENCY PROTECTION: Over Frequency Protection and under frequency.
MOTOR PROTECTION
MOTOR PROTECTION

1. General
For small to medium-sized motors up to about 150 hp are:
- Fuses (for short-circuit)
- Thermal overload relay (for overload)
- Contactors

For larger, microprocessor protection relays should be considered.

These relays typically include:
- Thermal overload protection,
- Short-circuit protection
- Start-up and running protection
- Phase unbalanced protection
- Single-phasing protection
- Earth fault protection
- Under-current protection
2. Typical protective *settings for motors*

   a) Related to time

   **Long-time pick-up**
   - (1.15) times factor at motor full load current (FLA), encountering 90% voltage dip on motor starting.
   - (1.25) times factor at motor FLA factor for applications encountering 80% voltage dip on motor starting.

   **Long-time delay**
   - Greater: motor starting time at 100% voltage and the minimum system voltage.
   - Less: locked rotor damage time at 100% voltage and the minimum system voltage.
   - On high-inertia drives, it is common for the start time to be greater than the locked rotor withstand time.

Under these circumstances, set the time to permit the motor to start. Supplemental protection should be added for locked rotor protection. One example of this is a speed switch set at 25% of rated speed tripping through a timer to trip if the desired speed has not been reached in a pre-determined time.
(b) *Instantaneous pick-up*
- Not less than 1.7 times motor *long-time pick up rated ampere (LRA)* for medium-voltage motors.
- Not less than 2.0 times motor LRA for low-voltage motors.

(c) *Earth-fault protection*
- Minimum pick-up and minimum time delay for static trip units
- Core-balance CT and 50 relays set at minimum for medium-voltage, low-resistance grounded systems.
- Residually connected CT, and 50/51 for medium voltage, solidly grounded systems. Minimum tap and time dial equals 1 for 51 relay.
- Minimum tap (not less than 5 A) for 50 relay.

3- **Motor protective device**
- Molded Case Circuit Breakers (MCCB) are used for low voltage motors of high ratings.
- Miniature circuit breakers (MCB) for small motors.
- Fuses + contactor + thermal relay for L.V motors.
- For high voltage motor: H.V. circuit breaker and differential protection.
Example:
A 100hp, 480V, 0.85pf, 85% efficiency motor has starting-up to 5.9 rated current up to 8 second with voltage dip of 80% during starting. Select protection means for this motor.

Solution:

\[ \eta = \frac{P_{\text{out}}}{P_{\text{input}}} \Rightarrow P_{\text{inp}} = \frac{P_{\text{out}}}{\eta} = \frac{100 \times 746}{0.85} = 87.764 \text{kW} \]

\[ I_{\text{rated}} = \frac{P}{\sqrt{3}V \cdot \cos \phi} = \frac{87764}{\sqrt{3} \times 480 \times 0.85} = 124 \text{A} \]

Choose moulded case circuit breaker with both thermal and magnetic trips:

Thermal setting of MCCB:
Thermal pickup setting is: (100 to 125\%). \( I_{\text{rated}} \) = \( (1.25) \) times motor FLA

Choose 125\% \Rightarrow 1.25 \times 124 = 155 \text{A} \)

Magnetic trip = \( (8 - 1.25) \times I_{\text{rated}} \) = 6.75 \times 124 = 837 \text{A} \)

Circuit breaker rating = 2 \times I_{\text{rated}} = 2 \times 124 = 248 \text{A} \)

Choose MCCB TF250AF/100AT

(Not less than 2 times motor LRA for low-voltage motors).
Motors protection by fuses

Fuses are used for protecting small and medium size motors. To determine the fuse size the typical fuse time/current characteristics is used.

These characteristics represent fuse operation where the current is insufficient to operate the fuse in the first 1/4 cycle, or 0.005 s in a 50 Hz system. If the starting current of the motor is say 500 A and the run-up time 10s, then a 125 A fuse would be required. Examination of the fuse time/current characteristic shows that at 500 A the 125 A fuse would operate in 15s. The fuse one size lower, 100 A, would operate in 4 s at 500 A and is, therefore, not suitable.
To summarize
1. The fuse must be adequately rated to supply normal current to the circuit.
2. The rating must take into account any normal healthy overload conditions e.g. the starting of motors.
3. An allowance must be made if an overload occurs frequently.
4. There must be an adequate margin if discrimination between fuses is required.
5. The fuse must protect any equipment which is not rated at the full short-circuit rating of the power system, e.g. contactors, cables, switches, etc.

Example of fuse selection
A 415 V distribution system is shown in Fig.
a- Lighting load - 20 kW

$$I = \frac{20 \times 1000}{\sqrt{3} \times 415} = 27.8 \text{ A}$$

Select a 32 A fuse.
b- Heating load - 30 kW

\[ I = \frac{30 \times 1000}{\sqrt{3} \times 415} = 41.7 \text{ A} \]

Select a 50 A fuse.

c- Motor 30 kW

The motor input power is output power/efficiency, i.e. for 92% efficiency: then

\[ \text{Input power} = \frac{30}{0.92} = 32.6 \text{ kW} \]

Also the heating and lighting loads are at unity power factor whereas the motor power factor is, say, 0.83.

Therefore the motor full load current is

\[ I = \frac{32.6 \times 1000}{\sqrt{3} \times 415 \times 0.83} = 54.7 \text{ A} \]

The starting current of, say, 7 x full load current for 10 s is \( 7 \times 54.7 = 383 \) A.

From the time / current curve, an 80A fuse would withstand 383 A for only 6 s. Therefore a 100 A fuse, which would withstand 383 A for longer than 10s, would be necessary.
e- To provide discrimination the main fuse (A) must meet the following requirements.

i - It must carry the normal load"
\[27.8 + 41.7 + 54.7 = 124.2 \, A\]

ii- It must carry the load plus the starting current of the motor:
\[27.8 + 41.7 + 383 = 452.5 \, A\] for 10 s

From Fig. 125 A fuse would withstand 452.5 A for more than 10s.

Note: The pre-arcing \(I^2t\) must be greater than the total \(I^2t\) of the 100 A fuse. Figure 5 shows that a 160 A fuse would be required.
Bus Bars Protection
Bus Bars Protection

Bus Protection Schemes

Bus protection is used to protect switches, disconnects, instrument transformers, circuit breakers, and other bus equipment as well as the bus itself.

There are several methods of bus protection:

- Basic differential protection
- Differential protection with overcurrent relays
- Percentage differential protection
- High-impedance voltage differential protection
- Bus partial differential protection

All these methods are based on KCL, namely, that the sum of all current entering a node must be zero.

Consider the two situations for simple bus shown in Fig.1
Fig. 1 Simple bus arrangement

- For external fault: \( I_f = I_6 = I_1 + I_2 + I_3 + I_4 + I_5 \)
- For internal fault: \( I_f = I_1 + I_2 + I_3 + I_4 + I_5 + I_6 \)
Bus differential relaying Schemes:

1. **Basic differential system**

   A basic differential system is shown in Fig.2. All CTs must have same ratio and polarity such that the current circulate amongst them is zero (\(I_d=0\)) for all external faults. For internal fault current \(I_d=I_f\) will flow through the relay.

---

**Fig.2**
2. Bus Differential Protection with Overcurrent Relays

If the CTs behaved ideally, the differential system shown in Fig.2 would be very easy to implement using a simple over-current relay as shown in Fig.3.
3. Bus Protection with **Percentage Differential Relays**

A percentage restrain differential relay takes the fact that there may be error current in differential circuit. A simple percentage restrain differential relay is shown in Fig. 4.

![Diagram of percentage differential relay](image)

**Fig. 4**

Consider a load bus with three outgoing feeders as shown in Fig. 5. This bus is protected by differential relay with three restrain coil. The protection scheme shown for one phase only.
When no fault ($I_1 + I_2 = I_3$) then $I'_1 + I'_2 - I'_3 = 0$ (restrain current and relay not operate, but if $I'_1 + I'_2 - I'_3 \neq 0$ the relay will operate, and the fault is present.)
Example 1: For the system shown (bus protection by differential current relays) an external fault is occurred on feeder No.3. Find whether, the differential relay will operate or not.

![Diagram of electrical system]

- CB1, CB2, CB3
- 600:5 CTs
- OP coil
- I1, I2, I3
- 5,000A, 10,000A
- F No. 1, F No. 2, Feeder No. 3
\[ I_{F3} = I_{F1} + I_{F2} = 5,000 + 10,000 = 16,000A \]

\[ If_1' = 5,000 \times \left( \frac{5}{600} \right) = 50A \]

\[ If_2' = 10,000 \times \left( \frac{5}{600} \right) = 83.4A \]

\[ If_3' = 16,000 \times \left( \frac{5}{600} \right) = 133.4A \]

\[ I_{op} = If_1' + If_2' - If_3' = 50 + 83.4 - 133.4 = 0A \text{ (the relay will not operated)} \]

**Example 2:** Repeat example 1 when feeder number 3 supplies 7000A to the bus and an internal fault occurs

\[ I_F = I_{F1} + I_{F2} + I_{F3} = 5,000 + 10,000 + 7,000 = 23,000A \]

\[ If_1' = 50A \quad \text{and} \quad If_2' = 83.4A \]

\[ If_3' = 7,000 \times \left( \frac{5}{600} \right) = 58.34A \]

\[ I_{op} = If_1' + If_2' + If_3' = 50 + 83.4 + 58.3 = 191.7A \text{ (the relay will operated)} \]
4. Bus High-Impedance Voltage Differential Protection
5. Bus Partial Differential Protection